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The Journal Bearing Analysis Suite, A New Analytical Tool Applied and Presented

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ABSTRACT

Planetary gear systems with hydrodynamic journal bearings can efficiently achieve high gear reduction ratios with minimum space and weight. For optimal designs, analytical tools are needed which provide accurate journal bearing modeling capabilities.

At NASA Glenn a journal bearing is being prepared to support a compressor test. During check-out tests, a lubricant temperature problem came to light. As the unloaded bearing reached 6000 RPM, the lubricant exceeded the 93° C facility maximum. With a 30% increase in clearance, the bearings ran to 16,200 RPM; however, testing conditions entail 18,100 RPM with 9000 HP load.

A parametric study was performed to determine the effects of clearance and loading upon lubricant temperature. A 1-D analysis was used, followed by the newly developed 3-D Journal Bearing Analysis Suite. The new software package incorporates the Army/NASA PGear Journal Bearing code. An overview of suite features and study results is presented.

INTRODUCTION

The purpose of the investigation was first, to assist test engineers in determining a suitable journal bearing configuration, and second, to validate and present the new tool through the analysis of a real-world application.

In preparing for the compressor test, a gearbox inspection revealed journal bearing damage. The journal bearing was reconditioned and the lubricant was changed from Dexron to 20W gear oil (ISO 68). A zero-load facility check-out test was performed, and at 6000 RPM, the bearing oil temperature reached the facility safety limit of 93° C. In response the bearing clearance was increased 30% and run to 16,200 RPM with oil temperatures lowered by 3° C. As test conditions ultimately mandate peak speeds of 18,100 RPM and 9000 HP load, analytical guidance was desired to optimize the design and lower temperatures. Changes were possible on clearance, groove shape, oil flow and lubricant; therefore a trade-off assessment was needed.

The analytical strategy was to perform a cursory (1-D) look at the operating envelope followed by a more rigorous (3-D) assessment. For each analysis, parametric studies were run on clearance/load, and overlapped for validation.

The 1-D analysis focused on the shear-stressed induced temperature rise (no-load condition) and was performed using the (commercial) steady-state 360° journal bearing code called JOURNAL by Tevaarwerk [1]. This code employs a global coupling between hydrodynamic and energy equations. It is intended to provide a "quick estimate" of bearing performance for the design engineer.

The 3-D analysis focused on the hydrodynamic effects of the anti-whirl grooves using the new Journal Bearing Analysis Suite. This analysis incorporates the Army/NASA PGear Journal Bearing code, the first transient journal bearing code to implement the Jakobsson-Floberg-Olsson (JFO) cavitation model by Elrod and Vijayaraghavan [2]. It uses a mass conserving algorithm written by David E. Brewe of the U.S. Army at the NASA Lewis Research Center in 1983, and performs a thermo-hydrodynamic (THD) analysis of fluid film journal bearings with collocation across the film thickness at Lobatto points using Legendre polynomials. The algorithm allows viscosity variation through the film due to shear heating, pressure viscosity effects, and facilitates: aligned/misaligned bearings, heat conduction through the bearing (stationary surface), net heat flux through the journal (rotating surface), free convection to the bearing outside and end surfaces, several groove designs with groove mixing temperatures, transient or steady state analysis, rotating or dynamic loading, and either surface (i.e. journal or bearing) rotating.

This analysis is a full THD numerical procedure and has been shown to accurately predict the temperature and pressure distributions throughout the bearing circumference, when compared to experimental data [3].

The Journal Bearing Analysis Suite most uniquely features a modern Graphical User Interface (GUI) and facilitates intuitive use for inexperienced users. The GUI includes: a case manager, parametric study manager, notes manager, 2D/3D graphics, web-publishing, multimedia help and more.

RESULTS

Using the 1-D analysis, the full operational load map versus permutations of clearance was calculated and is presented in Fig. 1. The analysis was a conservative assessment, as all anti-whirl grooves were eliminated (the 1-D analysis can assess grooves; however, the journal/groove geometry was beyond the scope of current capability).

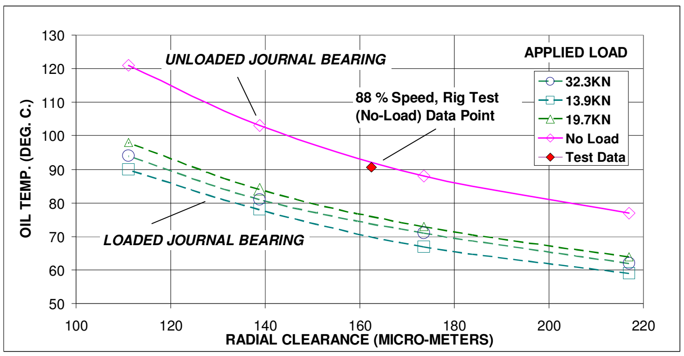

Figure 1. Load and clearance effects on temperature.

The most significant feature in Fig. 1 is the gap between the loaded cases and the no-load line. It had been expected that running the bearings without load would produce a significant shear-stress induced temperature rise; nonetheless, no data was available to provide quantitative guidance. The dramatic drop (15° to 30° C) in temperature (via applied load) rendered moot the need for bearing design optimization. The current clearance and all other clearances of interest were acceptably within the oil temperature limit criterion (93° C). It is noteworthy to mention how well the no-load line matched experimental data. As a caveat, the experimental point was not fully qualified since it was quasi-transient; nonetheless, it was close enough to steady state to obtain a qualitative assessment.

Though the 1-D analysis clarified the significance of shear induced heating, more rigorous analysis was worthwhile as the lowest clearance of interest produced temperatures coincident to the maximum (93° C).

Precursor to performing the more rigorous 3-D assessment, a code comparison exercise was performed using a common journal geometry/configuration. Using both analyses, the operating envelope was analyzed without grooves (side oil flow only).

Three (comparison) configurations of the journal bearing were analyzed and are presented in Fig. 2. Each band plotted represents the full operating envelope of applied loads plotted against permutations of clearance. In the upper band the Journal Bearing Suite and Tevaarwerk code are used to analyze the side-flow case. Throughout the range of load/clearance the results are in very good agreement and almost completely overlap.

In the middle band, the Tevaarwerk analysis was exercised with two oil supply holes which (together) had an effective area equivalent to the actual oil feed (or anti-whirl) groove area. The results reflect cooling from the more advantageous oil flow pattern afforded by the holes. No hydrodynamic effects from the holes were either calculated or applied. The general lowering of temperatures was reasonable.

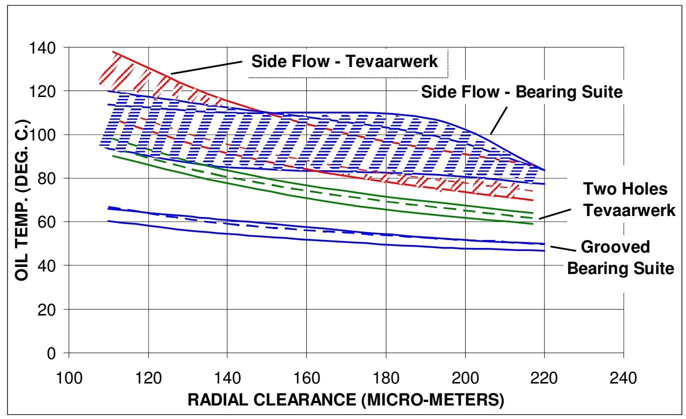

Figure 2. Load envelope vs. clearance.

The lowest band of temperatures represents a fully grooved (2 anti-whirl grooves, 90% axial length) configuration and was calculated using the Journal Bearing Analysis Suite. This band articulates the significance of hydrodynamic and thermal effects in determining accurate temperature profiles. The increased operating temperature margin revealed demonstrates the analytical precision that is necessary to develop highly optimized bearing systems that minimize space and weight.

All these results provide significant code validation and predict that the compressor test journal bearing will perform acceptably without modification.

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